DOCUMENT RESUME

ED 308 218 TM 013 564

AUTHOR Sugrue, Brenda M.; Thomas, Rex A.
TITLE Effects of Discovery and Expository Instruction on Recall and Transfer of Procedural Knowledge: Interactions with Learner Aptitude.
PUB DATE Mar 89
NOTE 16p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, March 27-31, 1989).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Aptitude; College Freshmen; Computer Assisted Testing; *Discovery Learning; Foreign Countries; Higher Education; *Instructional Effectiveness; *Recall (Psychology); Teaching Methods; *Transfer of Training
IDENTIFIERS *Expository Teaching; *Fluid Intelligence; Ireland; Procedural Knowledge

ABSTRACT

The interaction between fluid aptitude and two levels of instructional method (expository and discovery) was investigated. The methods differed in the completeness of the support provided for cognitive processing of procedural knowledge. Four performance outcomes were measured--immediate and delayed recall, and near and far transfer of the procedures learned. It was hypothesized that the discovery instructional method would promote transfer among learners with lower levels of fluid aptitude, but would interfere with the cognitive processing of learners with high fluid aptitude. Data were collected from 80 first-year students (randomly assigned to the two treatment groups) at the Thomond College of Education (Limerick, Ireland). Scores on a paper folding test provided a measure of fluid aptitude. Instruction was provided on procedures for solving a computer-based puzzle that involved changing the color configuration of a three-by-three square matrix. The results of stepwise regression analysis indicate that there was no interaction effect on immediate or delayed recall of procedures, or on far transfer of procedures. However, the discovery instructional method produced significantly more correct solutions to far transfer items than did the expository treatment, regardless of the level of fluid aptitude. Discovery instruction was best for learners with lower fluid aptitude, and expository instruction was best for learners with higher fluid aptitude. (Author/TJH)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED308218

Effects of Discovery and Expository Instruction on Recall and Transfer of Procedural Knowledge: Interactions with Learner Aptitude

Brenda M. Sugrue, Director, Sugrue & Associates Training
Rex A. Thomas, Iowa State University

Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA, March 31, 1989

ABSTRACT

This study investigated the interaction between fluid aptitude and two levels of instructional method (expository and discovery). The methods differed in the completeness of the support provided for cognitive processing of procedural knowledge. Four performance outcomes were measured: immediate and delayed recall, and near and far transfer of the procedures learned.

It was hypothesized that the discovery instructional method would promote transfer among learners with lower levels of fluid aptitude but would interfere with the cognitive processing of learners with high fluid aptitude. Data were collected from a sample of first-year university students (randomly assigned to the two treatment groups). Scores on a paper folding test provided a measure of fluid aptitude. Instruction was provided on procedures for solving a computer-based puzzle which involved changing the color configuration of a 3 X 3 square matrix.

The results of stepwise regression analysis indicated that there was no interaction effect on immediate or delayed recall of procedures, or on FAR transfer of procedures. However, the discovery instructional method produced significantly more correct solutions to FAR transfer items than did the expository treatment, regardless of level of fluid aptitude. The effect of instructional method on NEAR transfer WAS mediated by level of fluid aptitude: discovery instruction was best for learners with lower fluid aptitude and expository instruction was best for learners with higher fluid aptitude.

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Brenda Sugrue

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

TM013564

BEST COPY AVAILABLE

THEORETICAL FRAMEWORK

In the late 1950s and early 60s, much research was conducted to test the hypothesis that discovery learning leads to more active cognitive processing, better retention and farther transfer than does expository instruction. The hypothesis grew out of the cognitive theories of learning, such as that of Bruner (1960), which were in vogue. Learning began to be equated with transfer; the greater the degree of integration of new knowledge with old, the greater the subsequent ability to transfer the new knowledge to novel situations. At the time, theories of learning were vague, did not distinguish between types of knowledge, did not detail the nature of the cognitive structures in which knowledge is stored, and did not specify the mechanisms by which incoming information interacts with knowledge already in memory. It is not surprising that the early studies on discovery learning led to inconsistent findings and were wrought with conceptual, methodological, and semantic problems (Shulman & Keisler, 1966). The role of individual differences in learning from instruction was ignored, and there was a lack of consistency in the definition and labelling of independent and dependent variables.

In the past two decades, there have been significant advances in learning theory and research on instructional methods, minimizing many of these problems. The most important developments will now be described.

Cognitive Theories of Learning

The distinction between declarative and procedural knowledge has been clarified (Anderson, 1983; Merrill, 1983, Rumelhart & Norman, 1981). This distinction has become the basis for recent cognitive theories of how knowledge is acquired, stored in memory, retrieved, and used. For example, Anderson's (1983) theory of learning hypothesizes that all knowledge begins as declarative but, in order to be useable, must be transformed into procedural knowledge.

In Anderson's (1983) theory, the acquisition of procedural knowledge involves three stages: interpretation, compilation, and tuning. In the interpretive stage, task-specific declarative knowledge must be encoded from the external environment, or retrieved from declarative memory, into working memory. Task-independent productions use these declarative representations to produce the desired behavior or an approximation of the desired behavior. If the declarative information is in the form of direct instructions, then a person may just execute them one by one. If the information is less complete, then it may be treated as data for general problem solving procedures (e.g., means-ends analysis, working backwards) which produce coherent, domain-appropriate behavior. Compilation and tuning make the procedures learned more automatic and less errorful in their application.

Transfer of Learning

There has been a recent focus on transfer of learning and on the relationship between acquisition processes and subsequent levels of transfer of knowledge (Cormier & Hagman, 1987; Royer, 1979, 1986). The degree to which knowledge can be used in new contexts has become the operational definition of the degree to which

the knowledge has been actively processed and stored in generalizable procedures. The greater the extent of transformation of existing memory structures to accommodate new information, the greater the subsequent ability to transfer the newly-learned knowledge to novel situations.

Aptitude-Treatment Interaction

It has been concluded, from aptitude-treatment interaction (ATI) research, that no instructional method can be said to have absolute effects on the learning processes of students or on subsequent recall and transfer performance (Cronbach & Snow, 1977; Snow & Lohman, 1984). Acquisition processes and performance outcomes result from the interaction of instructional method with learner characteristics and learning task characteristics (declarative or procedural) (Cronbach & Snow, 1977; Voss, 1978). Learner characteristics, such as prior knowledge, level of general ability, and motivation interact with instructional method to produce different types of cognitive processing, knowledge structures in memory, and performance outcomes (Clark, 1989; Snow & Lohman, 1984; Tobias, 1987).

Instructional Methods

The concepts of high and low cognitive load instructional methods have been defined (Cronbach & Snow, 1977). High load instruction places a high information processing burden on the learner who must activate the interpretive stage of knowledge acquisition (Anderson, 1983) for him/herself in order to render the information more meaningful and transferrable. Expository instruction, such as that involved in the traditional lecture, is generally a high load method because it presents information to learners without any attempt to induce or monitor, in individual students, the kind of cognitive processing that would be necessary to reorganize and integrate the information in a meaningful way.

Low load instruction provides the cognitive processing support necessary to integrate new information with old. This is usually accompanied by incomplete information; learners compile complete procedural knowledge through actively processing the incomplete information presented. The interpretive stage of knowledge acquisition is supported. Learning in this manner facilitates the later retrieval, use, and transfer of procedures to novel problems (Royer, 1986). Low load methods model, or compensate for, the kind of cognitive processing that is required to become expert in a particular task domain. Some guided discovery instructional methods, such as interacting with analogical models or simulations are low load methods because they force learners to test their existing knowledge in relation to a task, only to find out that there are gaps in that knowledge (Hooper, 1986). The awareness of a "gap" or misunderstanding represents an opportunity for learning and the learner will actively modify his/her existing knowledge and compile it into more error-free and generalizable procedures (Anderson, 1983).

Fluid Aptitude

It now appears that Gf (fluid aptitude) is the essence of general ability, because

"it reflects response to the demand for flexible adaptation in the face of complexity both within and between tasks" (Snow & Lohman, 1984, p. 360). Learners with higher Gf appear to spontaneously use analogies and construct more general procedures during learning and problem solving than do learners with low Gf (Holyoak, 1984; Resnick, 1976; Sternberg, 1985). Learners with higher Gf more actively seek to construct personally meaningful and useful declarative and procedural knowledge. They are more likely to engage in the elaborative encoding, reorganization and continuous testing of their "provisional assemblies" (Snow & Lohman, 1984, p. 370) or procedures. Learners with lower Gf rely on simpler connections and non-semantic forms of elaboration such as maintenance rehearsal; their strategy demands more attention and memory resources and leaves stored procedures highly susceptible to interference from subsequent declarative inputs.

Disordinal Interactions

Recent reexaminations of ATI research in light of cognitive theories of learning have led to the discovery of a pattern of disordinal interactions. Instructional methods which seem to promote learning and transfer among learners with low aptitude appear to depress the learning of learners with high aptitude (Clark, 1989; Snow & Lohman, 1984). It seems that instruction which provides too much support for the interpretive stage of learning inhibits or interferes with the existing strategies of learners with higher Gf to integrate and reorganize knowledge for themselves (Clark, 1989; Snow & Lohman, 1984). Learners with higher levels of Gf do especially well under instruction that is significantly incomplete in terms of the support for cognitive processing provided, because it affords them opportunities for the spontaneous "active retrieval and adaptation of old assemblies [procedures] and, particularly, the invention of new assemblies [procedures]" (Snow & Lohman, 1984, p. 372), without imposing a strategy for doing so. Less is known about the type of instructional conditions that best help learners with lower levels of Gf to adapt and construct new procedures. Snow and Lohman (1984) prescribe the provision of instruction that is "explicit, direct, and structured in detail so as to provide the procedural knowledge as well as the conceptual [declarative] knowledge that such learners may not be able to provide for themselves" (p. 372).

The concrete analogical models and verbalization techniques employed by Mayer (1981) are an attempt to make explicit for learners the processes that high ability learners engage in spontaneously. Mayer's findings indicate that such externalization of effective acquisition processes are most effective in promoting transfer of knowledge for learners with low general ability. Many other studies, such as those by Dansereau et al. (1979), Gray (1983), Peterson, Janicki, and Swing (1979), and Yalow (1980), have compared the effects of high and low load instructional methods on learners with different levels of general ability, and have obtained results similar to those of Mayer (1981). This pattern of disordinal interactions between general ability and instructional method becomes less apparent as the level of transfer increases. Snow and Lohman (1984) suggest that this is because "neither flexible adaptation nor transfer can stretch to tasks demanding radically different procedures" (Snow & Lohman, 1984, p. 371).

Need for Research

There is a need for research to identify, more precisely, the nature of the interaction between the fluid aptitude of learners and the level of support for cognitive processing provided by instruction. Previous ATI studies have not controlled for differences in the prior knowledge of learners in relation to the learning tasks employed. Neither have previous ATI studies measured a variety of levels of transfer outcomes, or differentiated between declarative and procedural knowledge. The study reported here sought to improve on the design and methodology of previous ATI studies by focusing on the learning of procedures, selecting a learning task which would not be affected by prior knowledge, designing treatments that differed only in the degree of external support for cognitive processing provided, and measuring a variety of transfer outcomes. The general hypothesis tested was that level of fluid aptitude interacts significantly with instructional method. High Gf subjects achieve higher levels of transfer with expository instruction (a high cognitive load method); low Gf subjects achieve higher levels of transfer with discovery instruction (a low cognitive load method). In other words, discovery instruction compensates for lack of the aptitude that is positively correlated with ability to transfer, but interferes with higher aptitude for transfer.

METHOD

Subjects

The sample consisted of 80 volunteers from the first year students at Thomond College of Education, Limerick, Ireland. Subjects were matched on level of general ability and each matched pair was randomly assigned to treatment groups.

Learning Task

In order to minimize the effects of prior knowledge, a "meaningless" or "laboratory" type task, Challenger, was selected for the purposes of the study. The task has two main features: patterns (512 possible) and operations (3 possible). Challenger is a computer-based two-dimensional "puzzle" or set of tasks consisting of a 3 X 3 square matrix of cells, each cell being either green or white. The goal of the task is to change the pattern from an arbitrary arrangement of green and white cells to a matrix consisting of a single white cell surrounded by eight green cells:

G G G
G W G
G G G

Due to the symmetrical nature of the matrix, three distinct moves are possible:

1. if the cursor is on a corner cell, then that corner cell and the three cells surrounding it change color;
2. if the cursor is on the middle cell of any side, then all three cells on that side

change color;

3. if the cursor is on the center cell, then that cell and the middle cell on each side of the matrix change color.

An expert solver of the Challenger task would need to have acquired, stored and be capable of retrieving procedures for solution from all possible initial patterns of Challenger. One could become reasonably competent at the task by acquiring some specific and some general declarative and procedural knowledge, as well as some heuristics relating to solution of Challenger.

For the purposes of this experiment, instruction focused on a subset of the solution paths from three initial patterns, each requiring a minimum of six moves to be transformed to the goal state. The initial patterns of two of the paths were instances of one general pattern. The paths leading to the goal from these patterns would facilitate abstraction of more general rules for solving Challenger.

Treatments

The two instructional methods designed for use in this study were similar in the following respects:

1. Initial declarative information provided about the goal of the task; the operations, i.e., moves, permitted to attain the subgoals/goal of the task; and the entire sequence of moves to solve Path 1.
2. Initial opportunity (practice) to acquire procedural knowledge of the moves and their effects on the "state" of the task.
3. A progressive part method of instruction (Landa, 1974; Phye, 1986), working backward from the goal state.
4. The learner was restricted to one particular move in cases where there was an alternative move which would also lead closer to the goal.
5. No explicit reference was made to the symmetrical nature of the task.

The instructional methods designed for this study differed in the following manner. The expository instructional method was a high cognitive load method which provided complete information about the steps in each procedure together with practice, but little opportunity for error and no corrective feedback other than a display of the correct move when an incorrect move was attempted. The discovery instructional method was a low cognitive load method which initially presented incomplete information about the steps in each procedure and forced the learner to actively construct the steps through a process of trial, error, and implicit feedback. Learners in both treatment groups were able to perform the sequence of steps in each procedure without error at the end of the instructional program. A more complete description of the two training programs is available in Sugrue (1989).

Aptitude Measure

Following Snow and Lohman's (1984) argument, scores on the paper folding test from the Educational Testing Services set of Cognitive Reference Tests were used

as the measure of fluid aptitude in this study. Reliabilities for the paper folding test vary from .76 to .93 (French, Ekstrom, & Leighton, 1963). In this study the reliability (Cronbach's alpha) was .80. Work by Snow (1980) and others establishes the validity of the test as a measure of Gf.

Outcome Measures

Four outcome measures were employed: immediate recall, delayed recall, near transfer, and far transfer. Each test consisted of 3 items, i.e., paths. A time limit of seven minutes was imposed on each item in each test. The immediate recall test was taken immediately after instruction; subjects were asked to reproduce the three procedures that they had learned. The delayed recall test was taken one month after instruction; subjects were asked to reproduce the entire procedures that they had learned.

Neither of the transfer tests required transfer beyond the domain of Challenger. The initial patterns of the three near transfer items were either intermediate patterns or rotations of patterns in the paths on with instruction was provided. Thus, they were testing mastery of the basic skills (Royer, 1986) required for expertise in the Challenger task. The three far transfer items required generalization of those basic skills to solution from previously unseen initial patterns.

For each item in each test, solution or non-solution, number of moves made, and sequence of moves made during solution of the item were recorded by the computer. These data were used to form continuous measures of immediate recall, delayed recall, near transfer and far transfer of the procedures learned during instruction. The range of scores on any item was from 0 to 20. Since each test consisted of 3 items, the range of scores on any test was from 0 to 60. A full description of the formation of the continuous dependent measures is available in Sugrue (1989).

RESULTS

Acquisition Data

Expository instruction took less time than did discovery instruction (Mean for E group = 47.80 minutes; Mean for D group = 56.91 minutes; $t=4.09$, $df=78$; $p<.0005$), although both required similar numbers of moves (Mean for E group = 90; Mean for D group = 92; $t=.63$, $df=78$, $p=.532$).

Fluid Aptitude

There was no significant difference between the means ($t = .13$; $df = 78$; $p = .894$) or variances ($F = 1.65$; $df = 1, 78$; $p = .121$) of Gf scores for the two treatment groups.

Regression Analysis

The General Linear Model was used to test all ATI hypotheses relating to outcome measures (recall and transfer), following the procedure outlined by Pedhazer (1982, pp. 436-471). Four regression models with first order interaction terms were tested using the stepwise procedure.

None of the four models produced residuals which departed visibly from the assumption of normality; therefore, raw data were used for the dependent variables. From the correlations between treatment group and aptitude variables, no evidence of collinearity was found (the correlation between group and Gf was .0152). No outliers, i.e., data points with standardized residuals greater than 3 or less than -3, were detected.

Table 1 presents the proportion of variance accounted for (i.e, R-squared) by each successive predictor entered, and the overall F value and significance level for each of the models. The model was most appropriate for the variance in near transfer; the full model accounted for 26% of the variance.

Table 1. Summary of results for stepwise regressions

Criterion Variable[b]	R^2 for Successive Predictors Entered[a]			Overall F-value	df	p
	T	A	T*A			
I	.0156	.0895	.0959	2.68775	3,76	.0523
D	.0004	.0982	.1046	2.95989	3,76	.0375
N	.0023	.2238	.2637	9.07290	3,76	.0000
F	.0513	.0796	.0798	2.19690	3,76	.0953

[a] T = treatment; A = fluid aptitude; T*A = interaction.
[b] I = immediate recall; D = delayed recall; N = near transfer; F = far transfer.

The partial F-tests for the significance of the relationships between particular independent variables and each of the four dependent variables are presented in Table 2.

Table 2. Partial F-tests on single independent variables

Relationship of Interest [a]	F	df	p
I.T*A/T,A	-.734	1,76	.4652
I.A/T	2.499	1,77	.0146**
I.T/A	1.112	1,77	.2696
I.A	6.315	1,78	.0140**
I.T	1.239	1,78	.2910
D.T*A/T,A	-.736	1,76	.4642
D.A/T	2.891	1,77	.0050**
D.T/A	.130	1,77	.8966
D.A	8.478	1,78	.0047**
D.T	.0278	1,78	.8681
N.T*A/T,A	-2.030	1,76	.0459**
N.A/T,T*A	5.020	1,76	.0000**
N.T/A,T*A	2.072	1,76	.0417**
N.A	22.269	1,78	.0000**
N.T	.1820	1,78	.6708
F.T*A/T,A	.129	1,76	.8974
F.A/T	1.538	1,77	.1280
F.T/A	2.048	1,77	.0440**
F.A	2.367	1,78	.1280
F.T	4.218	1,78	.0433

[a]T = treatment; A = fluid aptitude; T*A = interaction; I = immediate recall; D = delayed recall; N = near transfer; F = far transfer; / = "after".

**Significant at or beyond .05 level.

Immediate Recall

The interaction effect was not significant (in full model, b3 = -1.069571, t = -.734, p = .4652, df=76); the relationship between fluid ability and immediate recall was similar in both treatment groups. The only main effect which was significant was that of fluid aptitude (in reduced model, b1 = 1.771849, t = 2.513, p = .0140, df = 78); the higher the level of fluid aptitude, the higher the level of immediate recall, regardless of instructional method. The most appropriate regression equation for both treatment groups was E(I) = 6.75 + 1.7718(A). This model accounted for 7.49% of the variance in immediate recall.

Delayed Recall

The interaction effect was not significant (in full model, b3 = -.955159, t = -.736, p = .4642, df = 76); the relationship between fluid ability and delayed recall was similar in both treatment groups. The only main effect which was significant was that of fluid aptitude (in reduced model, b1 = 1.814941, t = 2.912, p = .0047, df = 78); the higher the level of fluid aptitude, the higher the level of delayed recall, regardless of instructional method. The most appropriate regression equation for both treatment groups was E(D) = -3.19 + 1.8149(A). This model accounted for 9.8% of the variance in delayed recall.

Near Transfer

The effects of both fluid aptitude and treatment were significant (b1 = 2.897578, t = 5.020, p < .0005, df = 76; b2 = 27.74911, t = 2.072, p = .0417, df = 76) and there was a significant disordinal interaction effect between them, in relation to the near transfer criterion variable (b3 = -1.907998, t = -2.030, p = .0459, df = 76); the relationship between fluid aptitude and near transfer was significantly different in the two treatment groups. The separate equations were:

Expository: E(N) = -5.739012 + 2.897578(A)
Discovery: E(N) = 22.01009 + .98958(A)

The point of intersection of the two regression lines was
(22.01009 + 5.73901)/(2.897578 - .98958) = 14.54357.

Figure 1 shows a plot of the two regression lines. The discovery treatment was superior for students with lower levels of fluid aptitude up to 14.5, while the expository treatment was superior for students with higher levels of fluid aptitude (from 14.5 and up). The interaction model accounted for 26.37% of the variance in near transfer.

Far Transfer

There was no significant interaction effect between the two independent variables on far transfer (b3 = .113207, t = .129, p = .8974, df = 76); the relationship between fluid aptitude and far transfer was similar in both treatment groups. The only main effect which was significant was that of treatment (in reduced model, b1 = 5.745, t = 2.054, p = .0433, df = 78); there was a significant difference between the far transfer scores of the two treatment groups. The discovery treatment produced higher levels of far transfer than did the expository instructional method regardless of level of fluid aptitude of the students. The instructional method variable accounted for 5.13% of the variance in far transfer.

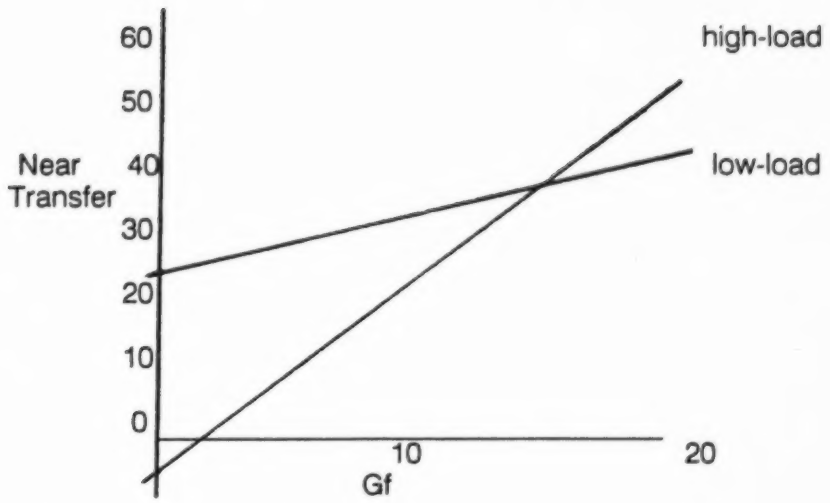

Figure 1. Regression of near transfer on Gf for each treatment group

DISCUSSION

The findings of this study concurred with much of current theory and previous research. In particular, the relationship between fluid aptitude and near transfer was much more pronounced when the instructional method placed the burden of cognitive processing on the learners themselves, than when support for appropriate cognitive processing was embedded in the instruction. Although the expository treatment broke the task down into its component steps, demonstrated the correct behavior at each step, and allowed the learners to practice the correct steps until they could reproduce the six steps in sequence, it did not encourage the learners to abstract more general heuristics for solving Challenger problems. The discovery treatment may have forced all learners to interpret each new step towards solution of Challenger by violating their expectations about the next move. Learners saw the results of the erroneous moves they made and had a chance to "find" the correct move, thereby integrating it more with their existing knowledge and rendering the procedure more generalizable. However, the expository instructional method was more appropriate for learners who had the fluid aptitude to make such generalizations without any support.

While fluid aptitude was highly correlated with delayed recall, the discovery treatment neither improved the delayed recall of the learners with lower Gf nor depressed the delayed recall of the learners with higher Gf, as it did in the case of near transfer. There was an equal amount of "forgetting" following each instructional method. It may be that a one-month interval in which there was absolutely no contact with the Challenger task overrode any of the benefits that the low-load treatment might

have had for the learners with lower Gf. Most studies that measure delayed recall only allow a couple of days to elapse before retesting (e.g., Kamouri, Kamouri, & Kirk, 1986). In the case of this study, when the task was presented one month later, it was almost a new learning experience and it was fluid aptitude rather than strategies acquired through instruction that influenced success. The fact that the transfer tests were taken immediately after the immediate recall test, which provided additional practice of the procedures, may partly explain why the effect of the low-load treatment on learners with lower Gf was so apparent in the near transfer test.

The finding that the discovery treatment led to greater far transfer for all learners, regardless of fluid aptitude, seems to contradict the theory that instructional methods that provide support for cognitive processing depress the transfer scores of learners with high fluid aptitude. However, it is consistent with Snow and Lohman's (1984) conclusion that the pattern of disordinal interactions between general aptitude and instructional method becomes less apparent as the level of transfer increases. In the case of the present study, this finding should be viewed with caution because the scores on the far transfer test were extremely low, indicating that, for the amount of instruction and practice provided, the far transfer test was much too difficult. Nevertheless, this finding could lead to the hypothesis that when farther transfer of procedures is required after instruction, then external cognitive processing support during initial learning is beneficial for all learners, regardless of fluid aptitude. This hypothesis may hold only for farther transfer WITHIN a particular domain of knowledge; it appears that fluid aptitude or metacognition IS related to transfer of knowledge BETWEEN domains (Corno & Mandinach, 1983; Snow & Lohman, 1984).

The results of this study lend support to the theory that the completeness of the cognitive processing support embedded in instructional methods is important in relation to disordinal ATIs. The results also lend further support to the theory that ability to transfer knowledge is a function of type of cognitive processing during learning. In terms of prescription for the design of instruction, this study indicates that when the task is procedural, the desired outcome is near transfer, and learners are deficient in fluid aptitude, then low load instruction is best. If the learners are high in fluid aptitude, they need little or no support for cognitive processing. However, more external support for cognitive processing may be required by all learners if farther transfer within a domain is required.

REFERENCES

Anderson, J. R. (1983). The architecture of cognition. Cambridge, MA: Harvard University Press.

Bruner, J. (1960). The process of education. Cambridge: Harvard University Press.

Clark, R. E. (1989). When teaching kills learning: Research on mathemathantics. In H. Mandl, E. De Corte, & H. F. Friedrich (Eds.), Learning and instruction: European research in an international context. Oxford, UK: Pergamon.

Cormier, S. M., & Hagman, J. D. (Eds.). (1987). Transfer of learning: Contemporary research and applications. New York: Academic Press.

Corno, L., & Mandinach, E. B. (1983). The role of cognitive engagement in classroom learning and motivation. Educational Psychologist, 18(2), 88-108.

Cronbach, L. J., & Snow, R. E. (1977). Aptitudes and instructional methods. New York: Irvington.

Dansereau, D. F., McDonald, B. A., Collins, D. W. , Garland, J., Holley, C. D., Diekhoff, G. M., & Evans, S. H. (1979). Evaluation of a teaching strategy system. In H. F. O'Neill, Jr., & C. D. Spielberger (Eds.), Cognitive and affective strategies (pp. 3-43). New York: Academic Press.

French, J., Ekstrom, R., & Leighton, P. (1963). Kit of tests for cognitive factors. Princeton, NJ: Educational Testing Service.

Gray, L. E. (1983). Aptitude constructs, learning procedures, and achievement. Unpublished doctoral dissertation, Stanford University, Stanford, CA.

Holyoak, K. J. (1984). Analogical thinking and intelligence. In R.J. Sternberg (Ed.), Advances in the psychology of human intelligence (Vol. 1). Hillsdale, NJ: Erlbaum.

Hooper, E. J. (1986). Using programming protocols to investigate the effects of manipulative computer models on student learning. Unpublished doctoral dissertation, Iowa State University, Ames, IA.

Kamouri, A. L., Kamouri, J., & Smith, K. H. (1986). Training by exploration: Facilitating the transfer of procedural knowledge through analogical reasoning. International Journal of Man-Machine Studies, 24, 171-192.

Landa, L. (1974). Algorithmization in learning and instruction. Princeton, NJ: Educational Technology Publications.

Mayer, R. E. (1981). The psychology of how novices learn computer programming. Computing Surveys, 13(1), 121-141.

Merrill, M. D. (1983). Component display theory. In C. M. Reigeluth (Ed.), Instructional-design theories and models: An overview of their current status. Hillsdale, NJ: Erlbaum.

Pedhazer, E. J. (1982). Multiple regression in behavioral research: Explanation and prediction (2nd ed.). New York: Holt, Rinehart and Winston.

Peterson, P. L., Janicki, T. C., & Swing, S. R. (1979). Aptitude-treatment interaction effects of three social studies teaching approaches. American Educational Research Journal, 17(3), 339-360.

Phye, G. D. (1986). Practice and skilled classroom performance. In G. D. Phye, & T. Andre (Eds.), Cognitive classroom learning: Understanding, thinking, and problem solving (pp. 141-168). Orlando, FL: Academic Press.

Resnick, L. B. (1976). The nature of intelligence. Hillsdale, NJ: Erlbaum.

Royer, J. M. (1979). Theories of the transfer of learning. Educational Psychologist, 14, 53-69.

Royer, J. M. (1986). Designing instruction to produce understanding: An approach based on cognitive theory. In G. D. Phye, & T. Andre (Eds.), Cognitive classroom learning: Understanding, thinking, and problem solving (pp. 83-113). Orlando, FL: Academic Press.

Rumelhart, D. E., & Norman, D. A. (1981). Analogical processes in learning. In J. R. Anderson (Ed.), Cognitive skills and their acquisition (pp. 335-360). Hillsdale, NJ: Erlbaum.

Shulman, L. S., & Keisler, E. R. (Eds.). (1966). Learning by discovery: A critical appraisal. Chicago, IL: Rand McNally.

Snow, R. E. (1980). Aptitude processes. In R. E. Snow, P. Federico, & W. Montague (Eds.), Aptitudes, learning, and instruction: Vol. 1. Cognitive process analyses of aptitude (pp. 27-63). Hillsdale, NJ: Erlbaum.

Snow, R. E., & Lohman, D. F. (1984). Toward a theory of cognitive aptitude for learning from instruction. Journal of Educational Psychology, 76(3), 347-376.

Sternberg, R. J. (1985). Beyond IQ. Boston, MA: Cambridge University Press.

Sugrue, B. M. (1989). Differential effects of high and low cognitive load instructional methods on recall and transfer of procedural knowledge. Unpublished doctoral dissertation, Iowa State University, Ames, IA.

Tobias, S. (1987). Learner characteristics. In R. M. Gagne (Ed.), Instructional Technology: Foundations (pp. 207-232). Hillsdale, NJ: Erlbaum.

Voss, J. (1978). Cognition and instruction: Toward a cognitive theory of learning. In A. Lesgold, J. Pelligrino, S. Fokkema, & R. Glaser (Eds.), Cognitive psychology and instruction (pp. 13-26). New York: Plenum.

Yalow, E. S. (1980). Individual differences in learning from verbal and figural materials (Tech. Rep. No. 12). Stanford, CA: Stanford University, Aptitude Research project, School of Education.